Flux tube emergence from the convection zone to the corona: HINODE observations and 3D simulations

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Paper in Apj and work in preparation
Chromosphere: Observational evidence from Hinode

References: V. Hansteen et al. PASJ 2007
Observational findings

- Flux emergence.
- Enlarged granulation in photosphere
- Large dark granules in Ca II
- Bright points in the boundary of large granules
- Darkening in Transition Region (He II)
- ... and Corona (Fe XII)
- Whole process takes the order of one hour.
The MHD equations: OSC

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0
\]

\[
\frac{\partial e}{\partial t} + \nabla \cdot (eu) + p \nabla \cdot u = \nabla \cdot F_r + \nabla \cdot F_e + \eta j^2 + Q_{visc}
\]

\[
\frac{\partial B}{\partial t} = \nabla \times (u \times B) + \eta \nabla^2 B
\]

\[
\frac{\partial \rho u}{\partial t} + \nabla \cdot (\rho uu + \tau) = -\nabla p + j \times B - g \rho
\]

Equation of state:  Tables based on the Uppsala Opacity Package

T, P, opacity (\(\chi_i\)), destruction probability (\(\varepsilon_i\)), and bin average of the Plank function (\(B_i\)) in each opacity bin i as functions of (e/\(\rho\)) and density.
Initial Setup

- Chromosphere
- Photosphere
- Transition region
- Corona

256x128x160 points
32 km dx, dy
32 km dz except in corona
16x8x16 Mm
Injection of field at the bottom boundary

\[ \frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E} \]

set electric field at boundary to strive for desired field:

\[ E_x^n = E_x - \frac{\Delta(B_y)}{\tau} \Delta z \quad \Delta(B_y) = B_y^n - B_y \]

For example flux tube with twist

\[ \mathbf{B}_{long} = B_0 \exp \left( -\frac{r^2}{R^2} \right) e_z \]

\[ \mathbf{B}_{trans} = \mathbf{B}_{long} r q e_\phi, \]

\[ r = \sqrt{(x-x_o)^2 + (z-z_o)^2} \quad \lambda = q R. \]
Initial Setup: Evolution

256x128x160 points
32 km dx, dy
32 km dz except in corona

Corona

Transition region

Chromosphere

Photosphere
Granulation pattern in photosphere:
Expansion, collapsed and bright points.
Agree with M. Cheung et al. 2007
Chromosphere:
Shock dominated - Magnetic dominated
(900km)
Chromosphere: Cool regions and expansion of the Transition Region

\[
\log_{10} (pg) \text{ at } y = 0.00 \text{ [Mm]} \text{ t = 21.3 [hs]}
\]

\[
\log_{10} (tg) \text{ at } y = 0.00 \text{ [Mm]} \text{ t = 21.3 [hs]}
\]
Ca II from the limb:
Spicules, Jets and rain
Spicules, Jets and coronal rain

evolution in temperature
Conclusions

- In photosphere increase in granular size and deformation, adiabatic cooling, etc, as found earlier by eg Cheung et al. 2007. Collapsed granulation and bright points in boundaries of the rising tube.

- At greater heights we find cool, dim, magnetized bubble that tends to expel chromospheric oscillations. Also greatly increased chromospheric scale height.

- Low density in the upper-Chromosphere followed by filament like structure.

- Reconnection with pre-existing field begins about half an hour after tube crosses photosphere. With banana structure and hot blobs at the foot points of the Loops.

- Other structures observed in the chromosphere: jets, spicules and coronal rain observed in the limb with Synthetic Ca II.